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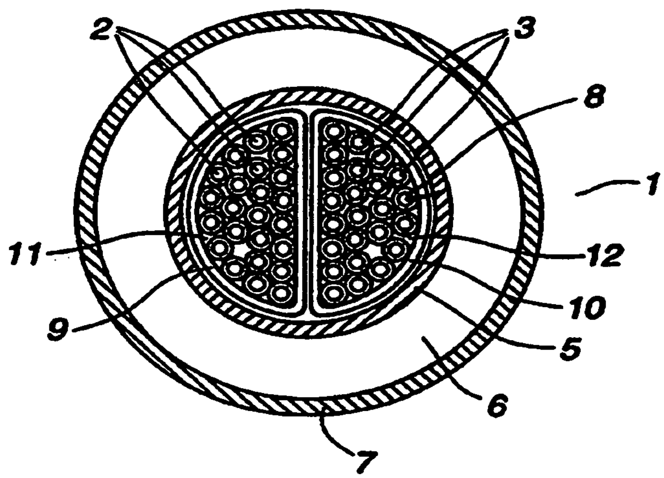
(57) Abstract

An electrical insulation (1) for a conductor (2, 3, 8), arranged in a plurality of turns for generating a magnetic field, comprising an insulant (6) of a solid material. The insulation is tubular and comprises an inner semiconducting layer (5) and an outer semiconducting layer (7). The semiconducting layers are adapted to contain between themselves an electric field. The joint between one of the semiconducting layers and the insulant (6) exhibits an adhesion which allows a retained mechanical contact in case of a structure-changing stress.



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Insulation for a conductor

TECHNICAL FIELD

The present invention relates to an insulation for, and a method for insulation of, a conductor arranged in a plurality of turns for generation of a magnetic field. In particular, the invention relates to an insulation in an electric circuit in a rotating electrical machine. By a rotating electrical machine is meant an apparatus which converts electrical energy into mechanical energy or vice versa. Such an apparatus comprises an electric circuit, a magnetic circuit, and a mechanical circuit. The mechanical circuit comprises two bodies which are movable in relation to each other. Upon a forced mechanical movement, a magnetic field is generated which is converted by the electric circuit into electrical energy. When supplying electrical energy, a magnetic field is generated which is converted by the mechanical circuit into mechanical energy. By a rotating electrical machine, as used in the following text, are meant both a generator and a motor.

The invention is preferably intended to be applied to a rotating electrical machine acting under high current and under high voltage, such as, for example, a generator which produces electric power. The mechanical circuit here comprises a stator and a rotor, whereby the rotor is rotatable in relation to the stator with one degree of freedom. The electric circuit may be arranged as a winding in either the rotor or the stator, or in both. By electrifying a winding, a magnetic field arises between the rotor and the stator. The magnetic field may be controlled and amplified by arranging magnetic cores in the stator and the rotor, which magnetic cores may be composed of, for example, laminated stacks of magnetically oriented sheets. However, the invention is not limited to an application on rotating electrical machines only, but may also be used in any electrical machines or apparatus

in which a conductor is to be insulated to be able to handle high voltages.

BACKGROUND ART, THE PROBLEM

To be able to describe the meritorious properties of the invention, a rotating machine in the form of a generator will be briefly described here. The most frequently used type of generator in force applications is a so-called synchronous machine. Such a machine comprises a rotatably journalled rotor with a rotor winding surrounded by a stationary stator with a stator winding. Both the rotor and the stator comprise magnetizable material, which preferably consists of laminated stacks of sheet. By supplying mechanical energy to the rotor shaft, the rotor is brought into a constant rotating movement. A current is caused to flow in the rotor winding, whereby a rotating magnetic field arises which generates a current in the stator winding.

The stator winding is arranged in radially embedded slots in the stator. The slots are axially oriented and rotationally symmetrically distributed along the stator. The stator winding comprises one or more series-connected conductors which are arranged in coils, which are located in the slots with two coils per slot. In ac machines a variation of the inductance across the cross section of the winding conductor arises. The greatest reactance is obtained at the bottom of the conductor and the main part of the current then tends to flow at the top of the conductor. To counteract such a current displacement, the conductor is divided into a plurality of strands which are insulated from one another. The division into strands does not prevent the inductance from varying for the different strands, but these have to be transposed, that is, change places. Such a transposition is usually carried out outside the stack of sheets but may also be arranged in the slots by means of a so-called Roebel transposition.

The choice of strand dimensions is a compromise between electrical and mechanical requirements. From an electrical point of view, it is preferable to have many strands since this reduces the current displacement, but from a mechanical point of view, the coils may become more difficult to manufacture and install. Few strands with large dimensions result in problems when, for example, a conductor is to be bent.

When insulating high-voltage windings, inter alia thermal, electrical, environmental and mechanical stresses must be taken in to consideration. These are usually called TEAM (Thermal, Electrical, Ambient and Mechanical) and influence the life of the insulation to a greater or smaller extent. From a thermal point of view, the insulation shall allow a temperature increase which may comprise 0-180°C within one hour. From an electrical point of view, the insulation shall permit a satisfactory electrical insulation without causing concentrations of the electric field. From the ambient, or environmental, point of view, the insulation shall not be influenced by dirt, ozone or condensation. Nor shall the insulation, from the environmental point of view, entail any environmentally harmful emissions during manufacture or operation, and, during scrapping, be capable of being recycled. Finally, from a mechanical point of view, the insulation shall allow the coils to be fixed to the stator but still allow movement during thermal expansion of the conductor and insulating material.

Although the voltage between the conductors is higher than between the strands, the conductor and strand voltages are relatively low. The strand and conductor insulation is therefore often simple to carry out. However, the coil itself must withstand the entire phase voltage which may amount to several kV. To this end, the coil is insulated against the stator by a main insulation. At high potential differences, a partial discharge, or PD, easily arises,

because of deformations of the field in the high electric field strength, this partial discharge being commonly referred to as corona. When corona occurs, ozone (O_3) arises, among other things, which is very aggressive towards organic compounds. Thus, corona causes a weakening of organic insulating materials and the main insulation therefore includes materials which are corona-resistant. One such material is mica, which is an inorganic compound and which withstands the attack of ozone.

The most commonly used insulating materials contain mica as main component. The mica is often embedded into a binder which is arranged on a tape-formed carrier. The material of the carrier and the binder may vary. A common embodiment of the main insulation is in the form of resin-saturated tapes containing flakes of mica, which are wound around the conductor and then cured in a furnace procedure. On top of the main insulation, a corona protector is arranged, which is to prevent external corona between the coil side and the slot wall.

Mica is a very brittle material which has low shear strength. Mica also has a thermal expansion which is one-fifth of, for example, that of copper. When loading an electrical machine, the winding is subjected to a temperature rise. The conductor, which is often made of copper, then tends to expand more than the insulation. Between the conductor and the insulation, a voltage thus arises because of the different thermal properties of the materials. Since mica has lower shear strength, fractures thus arise, which give rise to cavities in the insulation. Eventually, the cavities are filled with air and give rise to considerable deformations of the electric field. At such field concentrations, corona arises.

From US 5,066,881, an insulation for a generator is previously known, the main task of which is to arrange, in contact with the outside of the main insulation, a layer

which is capable of diverting charges to minimize corona. To this end, the insulation is surrounded by a semiconducting layer of a curable glass-fibre coating. This coating replaces a prior art grounding tape, which had the ability to divert charges for preventing corona. The new coating is stated to conform to the contour of the insulation in a better way and to better retain its semiconducting properties after the curing of the main insulation. In one embodiment, the semiconducting layer is applied to the upper and lower end regions of a coil on the inside of the main insulation. This embodiment is stated to entail an equalized electric equipotential around the ends. The known insulation does not add anything new to the prior art technique. Thus, it was already previously known to divert charges by arranging a semiconducting layer outside the insulation.

The predominant problem during insulation of a rotating electrical machine, such as a generator or a motor, is that the insulant and the conductor have different thermal expansion. In case of temperature variations, this implies that the insulant and the conductor are displaced in relation to each other such that cavities arise. The electric field is greatest nearest the conductor. Cavities thus arise where the risk of corona is greatest. In known generators, a certain amount of corona is accepted and instead the insulation is brought to contain mica which withstands discharges. As discussed above, mica has inferior mechanical properties. When the discharges occur, ozone is formed which attacks carriers and binders of the insulation, gradually resulting in the insulation bursting. Thus, after a certain time, the stator winding with the insulation must be replaced.

An additional problem in the known electrical machines where corona is accepted is that the discharges cause electromagnetic disturbances, which results in sensitive

electronic equipment being disturbed or, even, ceasing to function.

SUMMARY OF THE INVENTION

The object of the invention is to produce an insulation for a conductor arranged in a plurality of turns for generating a magnetic field. In particular, the invention relates to an insulation, arranged at a rotating electrical machine, which eliminates the occurrence of partial discharges (PD) and which has a long service life. The insulation shall also entail reduced maintenance and be more reliable than previously known insulation systems. From an environmental point of view, the insulation shall entail less environmentally harmful emissions during manufacture, use as well as scrapping. The object of the invention is also to suggest a method for insulation of a rotating electrical machine while achieving the objectives stated above. The insulation is in particular suitable when replacing a winding for an existing electrical machine.

The above object is achieved according to the invention by an insulation according to the characteristic features stated in the characterizing part of the independent claims 1 and 8 and with a method according to the characteristic features stated in the characterizing part of the independent method claim 9. Advantageous embodiments are stated in the characterizing parts of the dependent claims.

An electrical insulation is a medium or a material which, when placed between conductors of different potential, allows only a small or insignificant current to pass therethrough. At an increased potential between the conductors, also the electric field strength across the insulation increases. This also increases the risk of breakdown since the dielectric strength of the material is

exceeded. The electric strength is defined as the maximum voltage gradient which the material is able to withstand without breakdown occurring.

The dielectric breakdown for a gas is a result of an exponential multiplication of free electrons induced by the applied electric field. In a constant electric field, breakdown occurs at a voltage which is a function of the product of pressure and distance. Here, both in case of a small and a large such product, a gas has a high breakdown strength. In case of a small volume and a high pressure, an electron accelerated by the electric field is not able to pick up sufficient acceleration for starting a break-down by collision with other electrons. In case of a larger volume and a low pressure, the number of electrons is too small in order for a sufficient number of colli-sions to take place. Under the proper conditions, an electron is accelerated to such a speed that, upon colli-sion with other electrons, these are accelerated in a similar manner whereby an avalance-like breakdown occurs. In a practical application, the dimensioning dielectric strength for a gas is about 0.5 kV/mm. At lower electric field strengths, thus, no corona occurs in gas-filled cavities in the insulating material or between conductors and insulation.

Within high-field engineering, that is to say, when the electric field strength exceeds the dielectric strength for a gas, the risk of corona is obvious. A cavity which contains a gas in the insulant here entails spontaneous discharges. Thus, there is a considerable need to be able to minimize or completely exclude cavities in the insula-tion between conductor and insulation and to arrange the electric field such that field concentrations are avoided.

The insulation according to the invention comprises an elongated tubular insulant intended to enclose a conduc-tor. The insulant has one inner and one outer semicon-

ducting layer adapted to contain between themselves an electric field. The semiconducting layers cover the inside and the outside, respectively, of the insulant and are joined to the insulant with such an adhesion that the materials accompany each other in case of a structural change caused, for example, by thermal or mechanical stresses. Thus, the joint must not contain cavities, neither during manufacture nor in cases of stresses on the joined-together materials. Such an adhesion between the insulant and the two semiconducting layers is achieved by manufacturing them from the same materials. In case of a change in temperature, the materials then expand equally, whereby no, or only small, forces arise across the joint. However, adhesion may also be obtained between materials with different mechanical or thermal properties. For example, a joint with the adhesion aimed at may be achieved by heat treatment of the materials such that they float together at the joint into a homogeneous structure. Mechanical or thermal changes between the insulant and the two semiconducting layers are then absorbed as elastic or plastic deformations in the materials nearest the joint.

The inner layer is adapted to be galvanically or capacitively coupled to the conductor and the outer layer is adapted to be connected, for example, to ground or another controllable potential, whereby the electric field arisen between the conductor and ground is enclosed between the semiconducting layers in the insulation. Any cavities which may arise inside the insulation, because of a change in temperature or mechanical influence, do not give rise to any occurrence of PD. Between the conductor and the inner semiconducting layer, there is no potential difference.

By ensuring that corona does not occur, in the manner described above, the insulant may be made of an organic material without any addition of mica. The full insulating capacity of the material may then be utilized. Since no

ozone is formed which may weaken the materials, the thickness of the insulation may be made smaller. The insulation may therefore be made of a homogeneous material, for example a thermoplastic resin or a rubber mixture. One such suitable material is a crosslinkable polyethylene. The semiconducting materials may be made of the same material and be brought to contain a conducting dust, for example carbon black or powdered coal. The insulant with the two semiconducting layers may hence in a simple manner be applied to the conductor by, for example, extrusion.

The insulation system is especially intended for coils with a plurality of conductors, which may be divided into strands. The conductor and strand insulation is suitably made of a material which has a higher permittivity than the main insulation. By this arrangement, the insulation lying inside the inner semiconducting layer of the main insulation is able to change the electric field such that the concentration across the inner insulation becomes smaller. Instead the inner insulation "presses" out the equipotential lines in the field such that the larger concentration occurs within the main insulation. By this change of the field, the larger concentration is also brought to propagate over a larger area, the field concentration thus being thinned out.

In case of a lightning stroke, for example, an electrical rotating machine is subjected to an electric shock. During one or a few microseconds, the voltage then rises in the winding. Between conductors in a coil the potential difference may then amount to a few tens of kilovolts. Each conductor strand is surrounded by a thin strand insulation which is adapted to insulate the conductor strands from each other. The strand insulation is usually adapted to exhibit a good short-term strength against electric flashovers. Two conductor strands are thus insulated from each other with an insulation thickness

corresponding to two strand insulations. Likewise, between conductor strands associated with different conductors in a coil, two layer thicknesses of this insulation are arranged. Thus, flashovers in case of a shock between these occur only infrequently.

Since an insulation according to the invention encloses a plurality of conductors, the insulation between the semi-conducting layer and a conductor strand making contact therewith constitutes the thickness of the actual strand insulation only. The semiconducting layer is suitably connected to one of the conductor strands belonging to one of the conductors. The potential difference between the semiconducting layer and the conductor strand positioned nearest thereto is then only a few hundred volts during normal operation. The strand insulation constitutes sufficient insulation for preventing a flashover. In case of a shock, the potential increases instantaneously to several kilovolts. However, this potential change does not have time to develop into full strength in the semiconducting layer, so probabaly no flashover occurs in this case either.

The insulation referred to here permits a corona-free environment during normal operation. This implies that organic insulating materials may be utilized also for the strand insulation. This opens up new possibilities for considerably more elegant solutions of insulation than in an environment where corona occurs. Organic insulants with improved properties may be chosen and the insulating layers may be made thinner. To safely manage the insulation between the conductor strands and the inner semi-conducting layer, each conductor, including all the conductor strands, may be coated with an extra layer of high-quality insulating material.

BRIEF DESCRIPTION OF THE DRAWING

The invention will be explained in greater detail by description of an embodiment with reference to the accompanying drawing, wherein

Figure 1 shows a cross section through a coil for a stator winding which comprises an insulation according to the invention, and

Figure 2 shows a cross section of an insulation according to the invention with a circular cross section, said insulation enclosing two conductors.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A cross section through a typical winding coil for a rotating electrical machine is shown in Figure 1. The winding comprises a first conductor with a plurality of strands 2 and a second conductor also with a plurality of strands 3. The strands belonging to the respective conductor are surrounded by a strand insulation 4, which thus forms an insulating layer surrounding the stack of conductor strands. Surrounding the strand insulation 4 is an insulation 1, which comprises an insulating intermediate layer 6 with an inner semiconducting layer 5 and an outer semiconducting layer 7.

Figure 2 shows a cross section of an insulation 1 which encloses a first conductor 11 comprising a plurality of conductor strands 2 and a second conductor 12 comprising a plurality of conductor strands 3. The first conductor is surrounded by an insulating layer 9 and the second conductor is surrounded by an insulating layer 10. The surrounding insulation 1 comprises an insulating intermediate layer 6, an inner semiconducting layer 5 and an outer semiconducting layer 7. In the figures, the different layers have been intentionally made thick so as

to emphasize them. In reality, the semiconducting layers are thin and the insulating layers enclosing the conductor and the conductor strands are very thin. When manufacturing an insulation according to the invention, and conductors and conductor strands enclosed therein, the insulating layers tend to be compressed into a homogeneous insulation surrounding conductors and conductor strands.

One conductor strand 8 is galvanically or capacitively coupled to the inner semiconducting layer 5, such that this layer assumes the same potential as the conductor strand 8. The outer semiconducting layer 7 is in electrical connection with ground. By this arrangement, the insulation 1 is brought to contain the electric field which is formed between the conductor and ground. Of particular importance for the function of the insulation is that no cavities are formed between the inner semiconducting layer and the outer semiconducting layer. The insulating layer and the two semiconducting layers must be homogeneous and be in absolute mechanical contact with one another. The mechanical contact must also be maintained in case of a change caused by temperature variation or mechanical influence.

The outer semiconducting layer is adapted to distribute the ground potential across the outer limiting surface of the insulation. The outer semiconducting layer must thus cover the entire envelope surface. Similarly, the inner semiconducting layer is adapted to distribute the phase voltage connected to the conductor across the inner limitation of the insulation. The inner semiconducting layer must thus cover the entire inner limiting surface of the insulation. In this text, the term semiconducting material means a material which has considerably less conducting properties than a conductor but which still does not have such poor conducting properties that it may be regarded as an insulant. For example, the material

included in the two layers may have a resistivity in the interval 10^{-4} Ωm - 10^{4} Ωm, and especially in the interval 1 Ωcm - 100 Ωm.

The insulating intermediate layer is arranged from an insulating material which has a high electric strength, for example in excess of 7 kV/mm. By bringing both semiconducting layers to contain the whole potential difference between ground and phase and since no cavities are present between these, no partial discharges arise. The insulating intermediate layers may thus be arranged from an organic material, for example a thermoplastic resin or a rubber mixture. The two semiconducting layers may advantageously be made of the same material as the insulating intermediate layer, in which case a conducting dust, such as carbon black or powdered coal, is mixed into it. A suitable material is, for example, a cross-linkable polymer.

A considerable advantage in relation to prior art is obtained in that the insulating material no longer has to be supplied by winding. The polymeric material is advantageously supplied by extrusion, in which case the two semiconducting layers are supplied in the same process. This guarantees that cavities are completely excluded. It is not necessary for the insulant and the semiconducting layers to be made of the same materials. The decisive point is that no cavities arise between the materials. To this end, two separate materials may be joined together in such a way that the adhesion between them is maintained during thermal or mechanical influence. In case of materials with different properties, stresses arise in the region around the joint since one of the materials tends to expand more than the other. The adhesion should therefore be so strong that the joint is able to absorb these stresses. This can be done by elastic or plastic deformation of the materials on either side of the joint. An important advantage of the polymeric

material is that it is deformable and may be subjected, during its service life, to repeated mechanical deformation without jeopardizing the adhesion between the layers. Such materials may be simply fused together while supplying heat, such that the materials float together and form a homogeneous joint without cavities.

The strand insulation 4 is advantageously arranged with a dielectric constant which is higher than the dielectric constant for the main insulation. By this condition of the material, the strand insulation causes a change of the electric field such that the equipotential lines are displaced in a radial direction. The concentration of the electric field, which would otherwise be greatest nearest the conductor, is thereby displaced out from the centre and occurs in the main insulation between the two semiconducting layers. A larger distance from the centre also implies that the electric field is distributed over a larger area, which further weakens the concentration.

To withstand the load caused by an electric shock, for example from a lightning stroke, an insulating layer is arranged around each conductor. The potential difference between conductor strands associated with different conductors may, in the event of a shock, amount to a few tens of kilovolts. The short-time strength against flashovers of a simple layer of strand insulation is usually not sufficient for stopping a flashover between the conductor strand and the semiconducting layer. To safely maintain a sufficient resistance to such flashovers, the conductors are enclosed by an extra insulating layer 9, 10. It is also possible to create sufficient safety against flashovers by providing the inner semiconducting layer with such a resistance that no harmful potential is able to propagate in case of a shock.

CLAIMS

1. An electrical insulation (1) for a conductor (2, 3, 8), arranged in a plurality of turns for generating a magnetic field, comprising an insulant (6) of a solid material, **characterized** in that the insulation is tubular and comprises an inner semiconducting layer (5) and an outer semiconducting layer (7), which are adapted to contain between themselves an electric field, whereby the joint between one of the semiconducting layers and the insulant (6) exhibits an adhesion which allows a retained mechanical contact in case of a structure-changing stress.

2. An electrical insulation according to claim 1, **characterized** in that the inner semiconducting layer (5) is electrically connected to a conductor strand(8).

3. An electrical insulation according to claim 1 or 2, **characterized** in that the outer semiconducting layer (7) is connected to a controllable potential, preferably ground.

4. An electrical insulation according to any of the preceding claims, **characterized** in that the insulant (6) and the two semiconducting layers (5, 7) have the same thermal expansion.

5. An electrical insulation according to any of the preceding claims, **characterized** in that the semiconducting layers (5, 7) are made of a material with a resistance in the interval 1 Ωcm - 100 Ωm.

6. An electrical insulation according to any of the preceding claims, **characterized** in that the insulation is adapted to enclose a conductor with a substantially rectangular cross section.

7. An electrical insulation according to any of the preceding claims, **characterized** in that the insulant (6) and/or the semiconducting layers (5, 7) are in the form of crosslinkable polyethylene.

8. An electrical insulation (1) for a conductor (2, 3, 8), arranged in a plurality of turns and rotating in a magnetic field, comprising an insulant (6) of a solid material, **characterized** in that the insulation is tubular and comprises an inner semiconducting layer (5) and an outer semiconducting layer (7), which are adapted to contain between themselves an electric field, whereby the joint between one of the semiconducting layers and the insulant (6) exhibits an adhesion which allows a retained mechanical contact in case of a structure-changing stress.

9. A method for insulation of a conductor (2, 3, 8), arranged in a plurality of turns for generating a magnetic field, wherein an insulation comprising an insulant (6) of a solid material is brought to surround the conductor, **characterized** in that the insulation is tubular and is provided with an inner semiconducting layer (5) and an outer semiconducting layer (7), which are adapted to contain between themselves an electric field, whereby the joint between one of the semiconducting layers and the insulant (6) exhibits an adhesion which allows a retained mechanical contact in case of a structure-changing stress.

10. A method according to claim 7, **characterized** in that the insulant (6) and the two semiconducting layers (5, 7) are arranged of materials with the same thermal expansion.

11. A method according to claim 7 or 8, **characterized** in that the insulation is adapted to surround a conductor with a substantially rectangular cross section.

12. A method according to claim 7, 8 or 9, **characterized** in that the insulation and the semiconducting layers are

applied to the conductor by extrusion of crosslinkable polymer.

13. Use of an insulation according to claims 1-7 or a method for insulation according to claims 8-11 in a rotating electrical machine, in particular for replacing the windings in connection with renovation of such a machine.

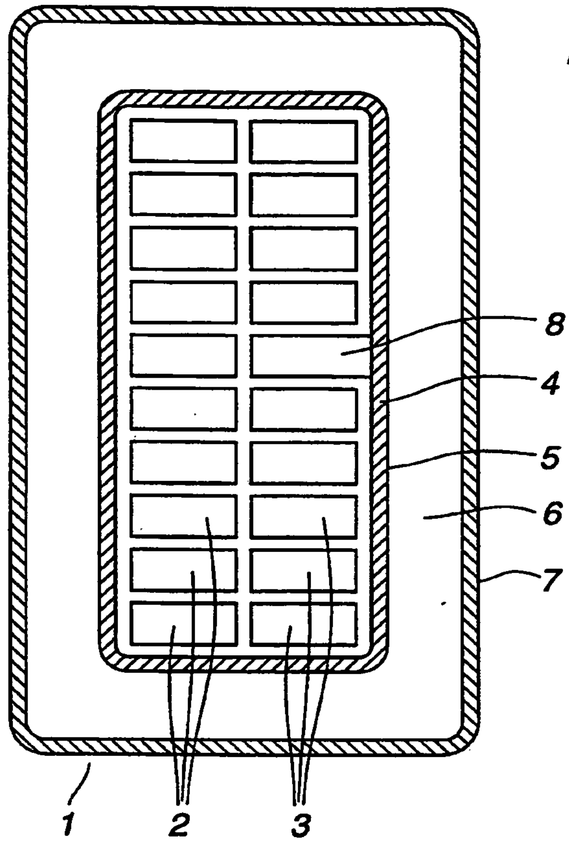

Fig. 1

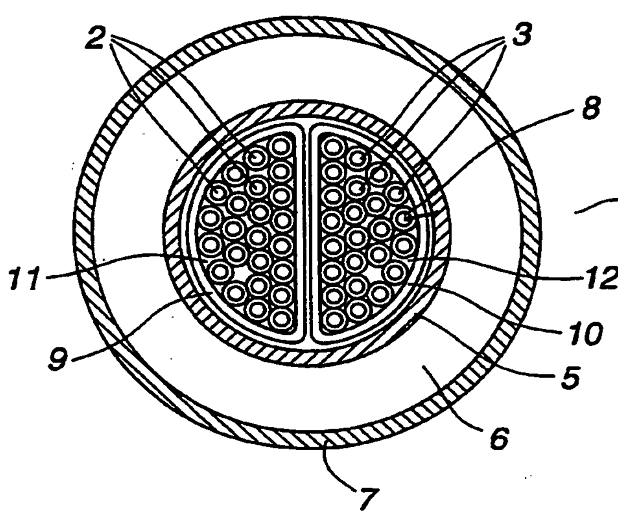

Fig. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/01715

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02K 3/40, H01B 9/02, H01F 5/06, H01F 27/34

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H01B, H01F, H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

QUESTEL: EDOC, WPIL, JAPIO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4403163 A (RAINER ARMERDING ET AL), 6 Sept 1983 (06.09.83), column 1, line 5 - line 40; column 3, line 67 - column 4, line 50, figure 1 --	1-13
A	EP 0490705 A1 (WESTINGHOUSE ELECTRIC CORPORATION), 17 June 1992 (17.06.92), column 7, line 11 - column 8, line 26, figure 3 --	1-13
A	US 3891880 A (HELMUT BRITSCH), 24 June 1975 (24.06.75), column 4, line 28 - line 47, figure 2 --	1-13

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
22 December 1998	07 -01- 1999
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INTERNATIONAL SEARCH REPORT

International application No.
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